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Computed tomographic assessment of equine maxillary cheek teeth anatomical relationships, and paranasal sinus volumes

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Abstract

Disorders affecting the equine maxillary cheek teeth and paranasal sinuses are relatively common, but limited objective information is available on the dimensions and relationships of these structures in horses of different ages. The aims of this study were to assess age-related changes in: the positioning and anatomical relationships of the individual maxillary cheek teeth with the infraorbital canal and maxillary septum and the volumes of the individual sinus compartments.

Computed tomography (CT) and gross examination were performed on 60 normal equine cadaver heads that were aged by their dentition. The intra-sinus position of cheek teeth, length of reserve crowns, relationship to the infraorbital canal and measurements of rostral drift, and sinus compartment volumes were assessed from CT images.

The findings included that Triadan 10 alveoli lay fully or partially in the rostral maxillary sinus (RMS) in 60% of cases. The infraorbital canal lay directly on the medial aspect of the alveolar apex in younger horses. The Triadan 11s' clinical crowns and apices drifted a mean of 2.48 cm and 2.83 cm more rostral to the orbit respectively, in the >15 years old vs the <6 years old age group. The mean volumes of sinus compartments ranged from 175 cm^3 for the caudal maxillary sinus (CMS) to 4 cm^3 for the ethmoidal sinus (ES). This information should be of value in the diagnosis and treatment of equine dental and sinus disorders and as reference values for further studies.

Keywords: Equine paranasal sinuses; computed tomography; dental anatomy; infraorbital canal, dental sinusitis

Introduction

The growing use of computed tomography (CT) has allowed a reassessment of the very complex and variable sinonasal and dental anatomy of the horse, that additionally becomes altered with disease. This three-dimensional imaging modality is increasingly used in the diagnosis of equine sinonasal (Morrow and others 2000, Henninger and others 2003, Solano and Brawers 2004), and dental disorders (Veraa and others 2009, Windley and others 2009, Buhler and others 2014), where it has been shown superior to conventional radiography in which superimposition of adjacent structures is problematic. The use of CT has also enabled new sinonasal disorders to be recognised (Dixon and others 2015)

Limited objective information is available on the position of maxillary cheek teeth alveoli in relation to individual sinus compartments (Dyce and others 2010, Sisson and Grossman 1953); on age-related eruption and rostral drift of cheek teeth and on the position of the infraorbital canal in relation to the cheek teeth alveoli, although such information would be of clinical value for investigating and treating sinus and dental disorders. The volumes and relationships of the individual paranasal sinus compartments, as assessed by semi-automated segmentation of CT data sets, has recently been reported (Brinkschulte and others 2013, Brinkschulte and others 2014), and a study of three-dimensional anatomy of Arabian foal paranasal sinuses (Bahar and others 2014) showed major age-related changes in sinus shapes and dimensions.

The purpose of this study was to quantify: the position of the cheek teeth alveoli in relation to individual sinus compartments; the poorly described, age-related rostral drift of cheek teeth; the eruption-related changes in the reserve crown length and the position of the infraorbital canal in relation to the alveoli and concho-maxillary ostium. An additional aim was to measure the volumes of the individual compartments in a large number of horses of different ages, using a different image processing software (Osirix, http://www.osirix-viewer.com/) [1] and breeds from previous equine studies (Brinkschulte and others 2013s; Bahar and others 2014) to provide further objective information, including the relationship between sinus and head volumes, and age-related changes in these complex and variable structures.

[1] www.osirix-viewer.com

Material and methods

Specimens

Head were available from two sources:

Group A

The heads of 54 horses freshly obtained from an abattoir, with unknown histories but similar in size to Thoroughbred heads had transverse CT images obtained, with the heads positioned on their mandibles, using a multislice CT scanner (Multislice CT scanner Siemens Volume Zoom, Munich Germany) in a helical scan mode using a 512x512 Matrix, 120 Kv, 300 mA, at a slice thickness of 1.5 mm. After image acquisition, the heads were frozen (-20^{0} C) and then sectioned transversely (48 heads) and sagittally (5 heads) at 5 cm intervals with a band saw. After thawing out, both sides of all transverse sections were visually examined for the presence of sinonasal or significant dental abnormalities.

Group B

Anatomical and CT images of a further 36 equine heads with unknown histories that had been freshly obtained from an abattoir were also included in this study. CT images were acquired using a 4th generation, Universal Medical System CT scanner, GE light speed ultras, Highland Heights, Ohio, USA, at 1.25 mm slice thickness, 120 kV, 300 mA. The CT images were examined for the presence of sinonasal disease or significant dental abnormalities.

Twenty-six of 54 heads (48%) in Group A had gross and/or imaging evidence of dental or sinonasal disease and were excluded from the study, leaving 28 heads in this group. Four of the 36 heads in Group B with imaging evidence of dental or sinonasal disease were also excluded, leaving 32 heads in this group (total of 60 normal heads).

These 60 heads were aged by clinical incisor examination using standard guidelines (Muylle 2011) along with CT examinations of cheek teeth reserve crown and root lengths and were placed into one of three age groups: <6 years old (Group 1: N=15), 6-15 years old (Group 2: N=21) and >15 years old (Group 3: N=24).

Image manipulation

Bone window CT data of the 60 heads were transferred as DICOM images to Osirix® imaging software which was used to perform multiplanar image reconstructions to allow identification and measurements of the sinuses and adjacent structures and 30 heads, including 10 randomly selected from each age group, were used for sinus and head volume measurements.

Sinus volume

Sinus compartment volumes were calculated using three-dimensional regions of interest (3D ROIs)/Volume, Osirix®) by outlining the internal boundary of each sinus on transverse images using every image slice (1.5mm slice thickness) of that compartment as previously described (Liuti and others 2015), using a bone window (70 algorithm) which accurately differentiated bone from mucosa: 15 to 90 slices were used per sinus compartment.

Head volume

The “volume” of each skull was calculated as described (Liuti and others 2015). To allow comparison of the head sizes in the study population with head sizes of known breed, CT measurements were compared with equivalent measurements from CT images of the heads of 12 Thoroughbreds of known age (<6 years old, (n=4); 6-15 years old, (n=4); >15 years old, (n=4) without identified head disorders.

Position of cheek teeth in relation to maxillary sinus compartments

Transverse and sagittal CT slices were used to identify the location of each maxillary cheek tooth alveolus in relation to the RMS and CMS compartments; the maxillary septum and orbital bone.

Rostral drift of the maxillary cheek teeth

Sagittal CT slices were used to assess the distance between a reference line drawn at the most rostral aspect of the orbital rim (Fig. 1, line C) that was perpendicular to the a line of best fit on the maxillary cheek teeth occlusal surfaces – which have a variable dorsal slope at the level of the caudal cheek teeth (Curve of Spee) (Fig. 1, line D) and the caudo-lateral (buccal) aspect of the occlusal surface of the caudal maxillary cheek teeth (Triadan 11) (hereafter termed the “caudal aspect of the Triadan 11 clinical crown”) (Fig. 1 lines Y) and the caudal aspect of the lateral root of the Triadan 11 (termed the “caudal aspect of the Triadan 11 apex”) (Fig. 1 lines X) to the reference line C. The reference line C was considered point “0” and the distances rostral to it (left side of the line) were considered negative and the ones caudal to it (right side of the line) positive.

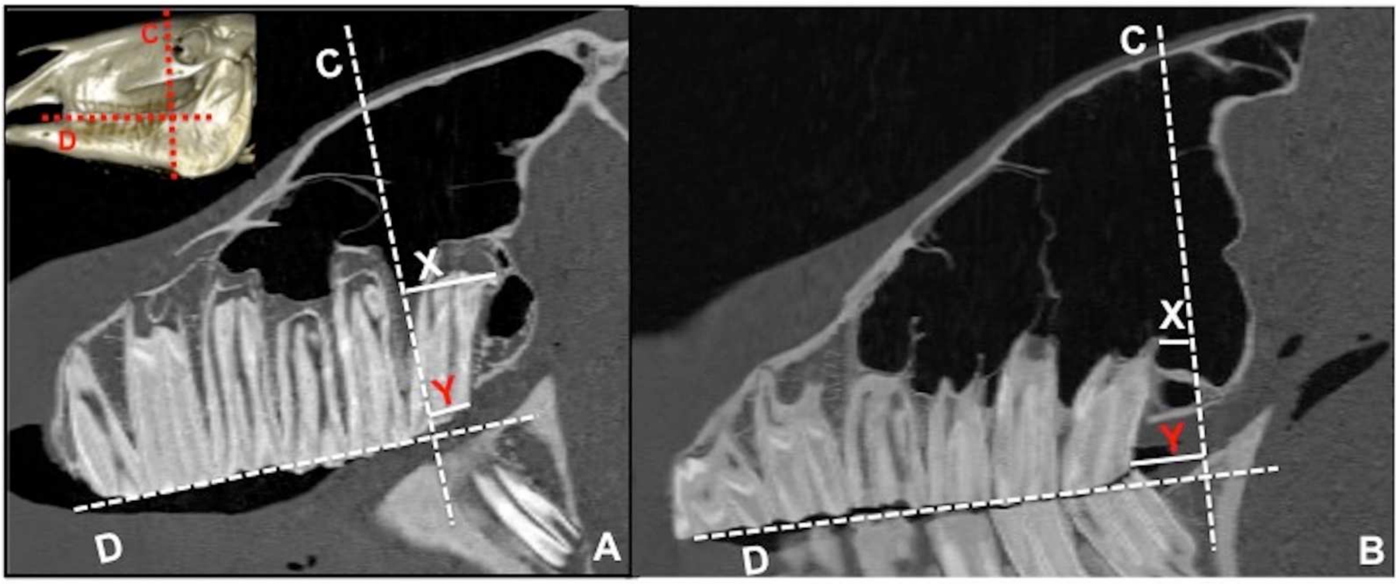

Fig. 1 **Sagittal CT image of a 4 years old (A) and a 16-year-old horse (B). Note the fixed orbital reference line (C) and the line parallel to the maxillary cheek teeth occlusal surface (D). The distance between the caudo-lateral aspect of the Triadan 11s occlusal surface to the orbital reference line (Y) and the distance between the caudo-lateral aspect of the caudal tooth root of Triadan 11 and the orbital reference line (X) were measured. Almost all of the Triadan 11 in the younger horse is caudal to the orbital reference line, whilst all of the Triadan 11 is rostral to this reference line in the older horse. Note the 3D volume rendering image of the skull in figure 1A, showing the reference line C and D**

Length of reserve dental crown

Transverse CT slices were used to assess the length of the reserve crown (unerupted, enamel-containing areas of teeth) on both palatal and buccal aspects of all maxillary cheek teeth. The occlusal surface is angulated palato-bucally (transversely), and this angle also varies between the different Triadan positions (Brown and others 2008). Consequently, the mean of buccal and palatal measurements was used to measure the length of each reserve crown using an "open polygon" tool, i.e. a linear measurement composed of a series of straight-line segments; if the surface to be measured was curved, multiple line segments were drawn adjacent to each other until the desired endpoint was reached. (Fig.2). The reserve crown length was calculated as the mean of the palatal and buccal lengths.

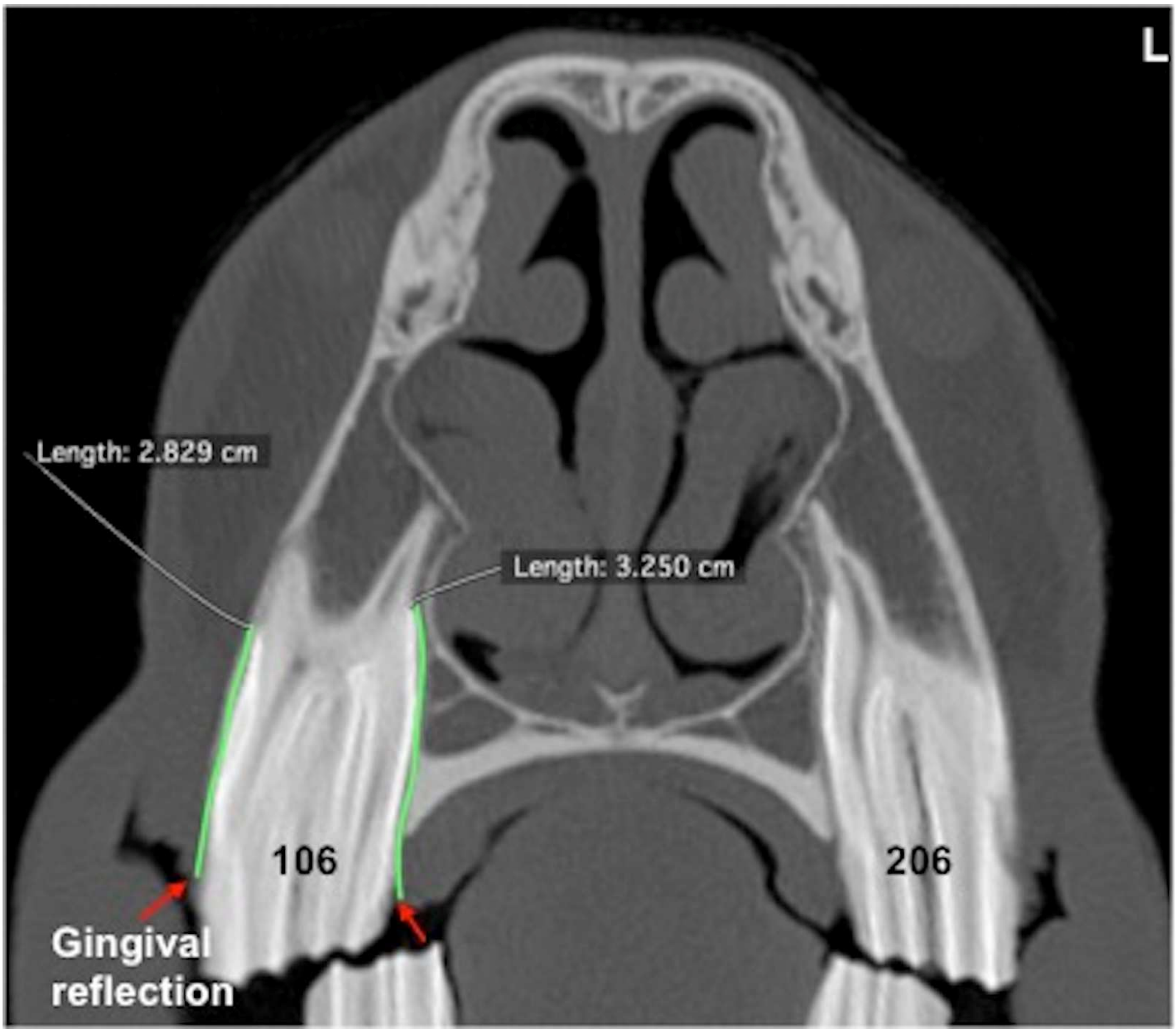

Fig. 2 **Transverse CT image of an adult horse at the level of Triadan 09. Note the difference in the lengths of the palatal and buccal aspects of the reserve crown, due to occlusal angulation. The green lines on the buccal and palatal aspects of the tooth**

represent joined points created by an open polygon tool that was used to measure these curved structures. The sites of gingival reflection (boundary between clinical and reserve crown) on the palatal and buccal aspect of this tooth has been indicated with red arrows *L: Left*

Position of the infraorbital canal (IOC) in relation to the cheek teeth alveoli; and ventral and conchal sinus walls (conchomaxillary ostium)

Transverse CT slices were used to document the anatomical position of the IOC in relation to the 08-11 maxillary cheek teeth alveoli bilaterally, including its height above the rostral and caudal roots of these teeth (Fig.3)

The width of the conchomaxillary ostium at the rostral aspect of Triadan 10 and middle of Triadan 11 were also measured at sites both horizontal and vertical to the infraorbital canal. (Fig.4)

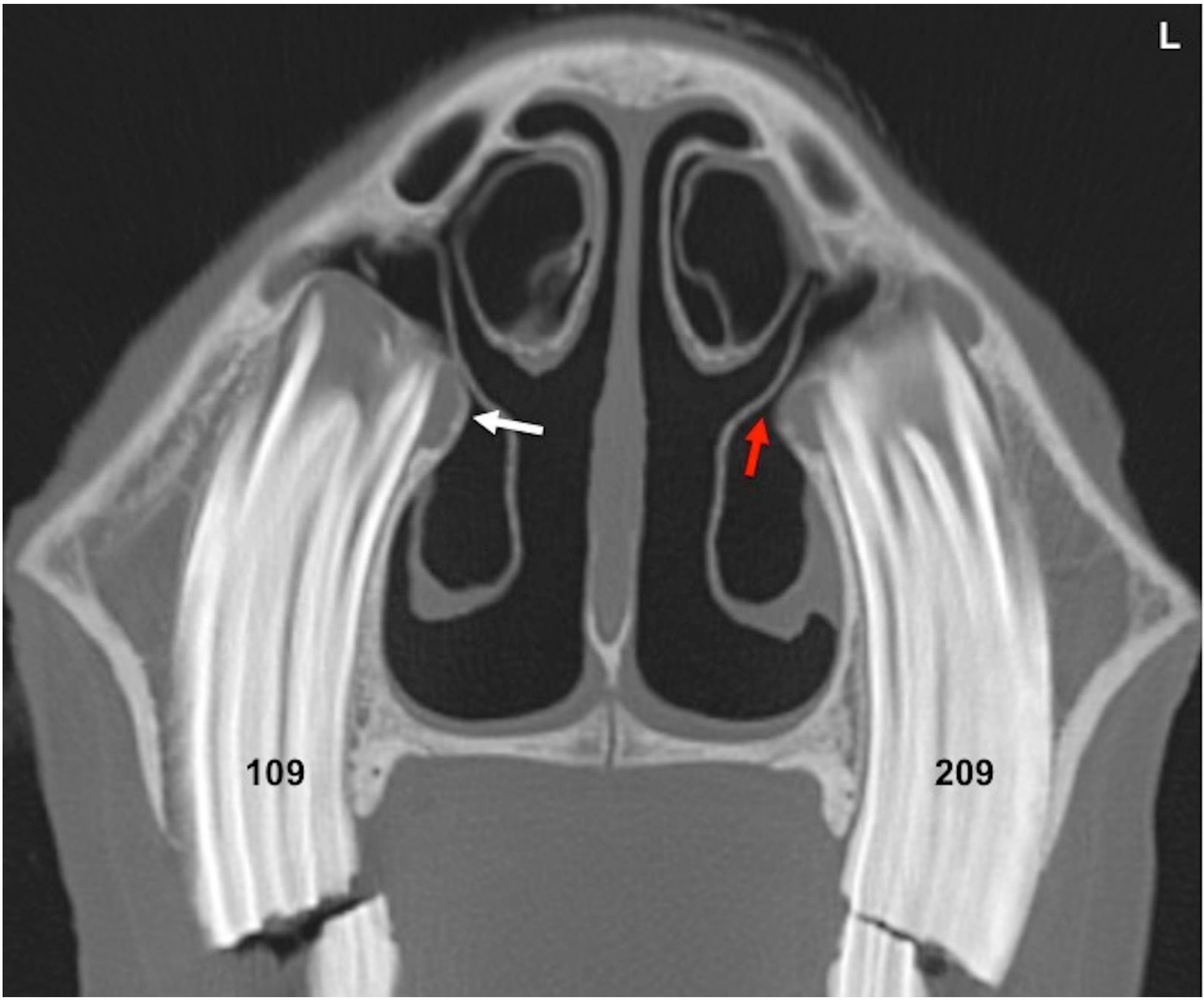

Fig. 3 **Transverse CT image of a 1-year-old horse at the level of 09. Note the mediodorsal location and the intimate relationship of the infraorbital canals (white arrows) with the dental apex. Note also the restricted concho-maxillary drainage in this young horse (red arrow).** ***L: Left***

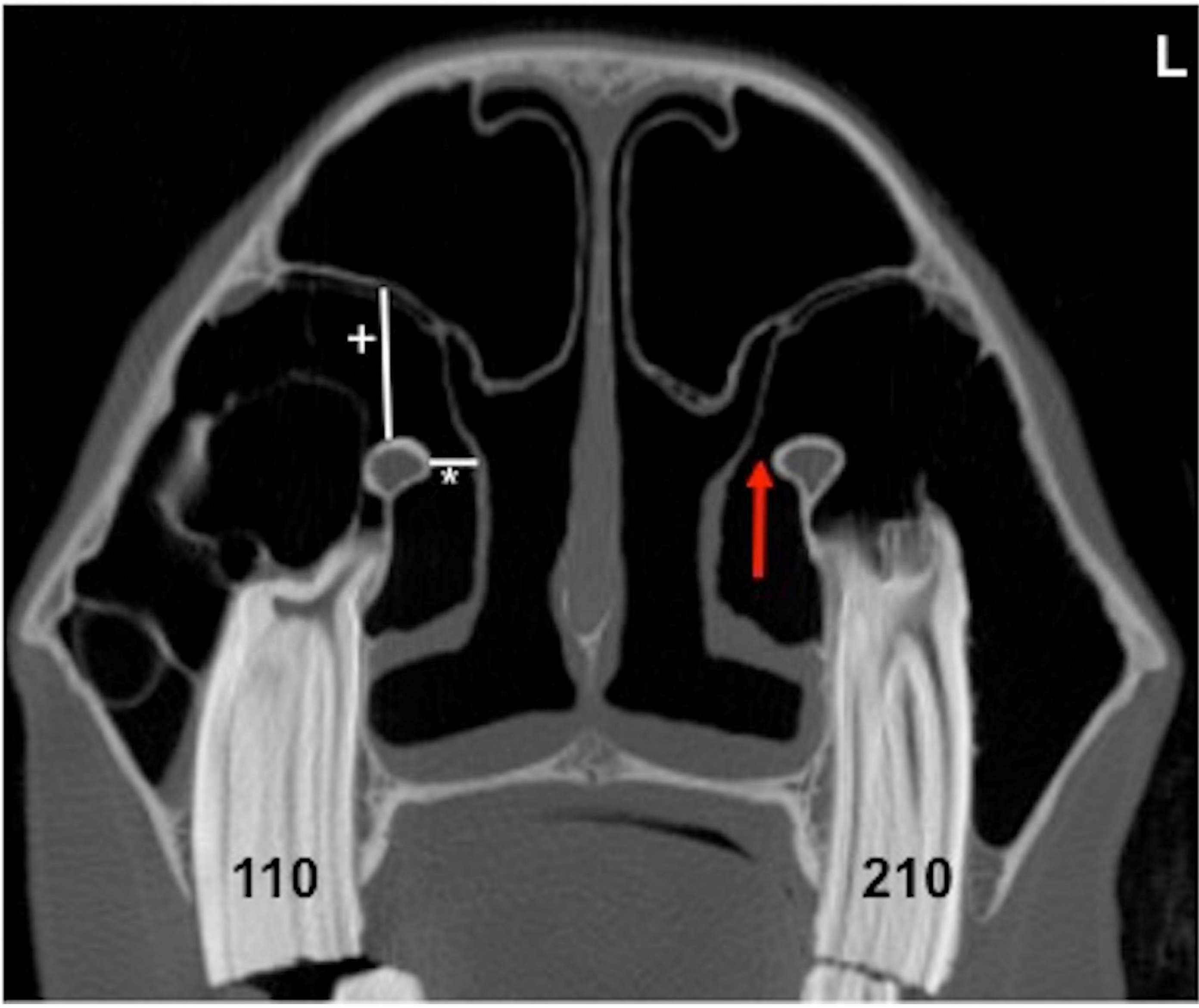

Fig. 4 **Transverse CT image of a 12 years old horse at the level of Triadan 10. Note the distance between the IOC and the medial (*) or dorsal (+) VCS wall.; note the conchomaxillary aperture (red arrow). The horizontal and vertical line to the IOC represent the size of the conchomaxillary ostium.**

L: ***Left***

Statistical analyses

Sinus and head volume and linear measurements were assessed for normality using Shapiro-Wilk tests, the results of which were used to guide appropriate statistical test choice.

Paired T-tests were used to examine for significant differences in volume of the 7 sinus compartments, and in length measurements between the left and right sides of each head.

To assess the relationships between mean sinus compartment and head volumes, scatter plots with lines of best fit were produced. Linear regression was performed to assess whether the mean volumes of individual sinus compartments and total head volumes were significantly associated.

To assess for significant differences in sinus compartment volumes, Triadan 11 positions relative to the orbital bone and crown length between age groups, measurements adjusted to head size were calculated as follows:

Adjusted sinus volume = (mean measured sinus volume / measured head volume) x 100.

Adjusted Triadan 11 position (both apical and occlusal) = (mean measured length / measured head length) x 100.

Adjusted crown length = (mean measured crown length / measured head height) x 100.

Box and whisker plots were produced to visualise the spread of adjusted sinus volumes between the three age groups (Fig 5).

ANOVAs were performed to determine whether adjusted sinus volumes, Triadan 11 positions and reserve crown lengths differed significantly between age groups.

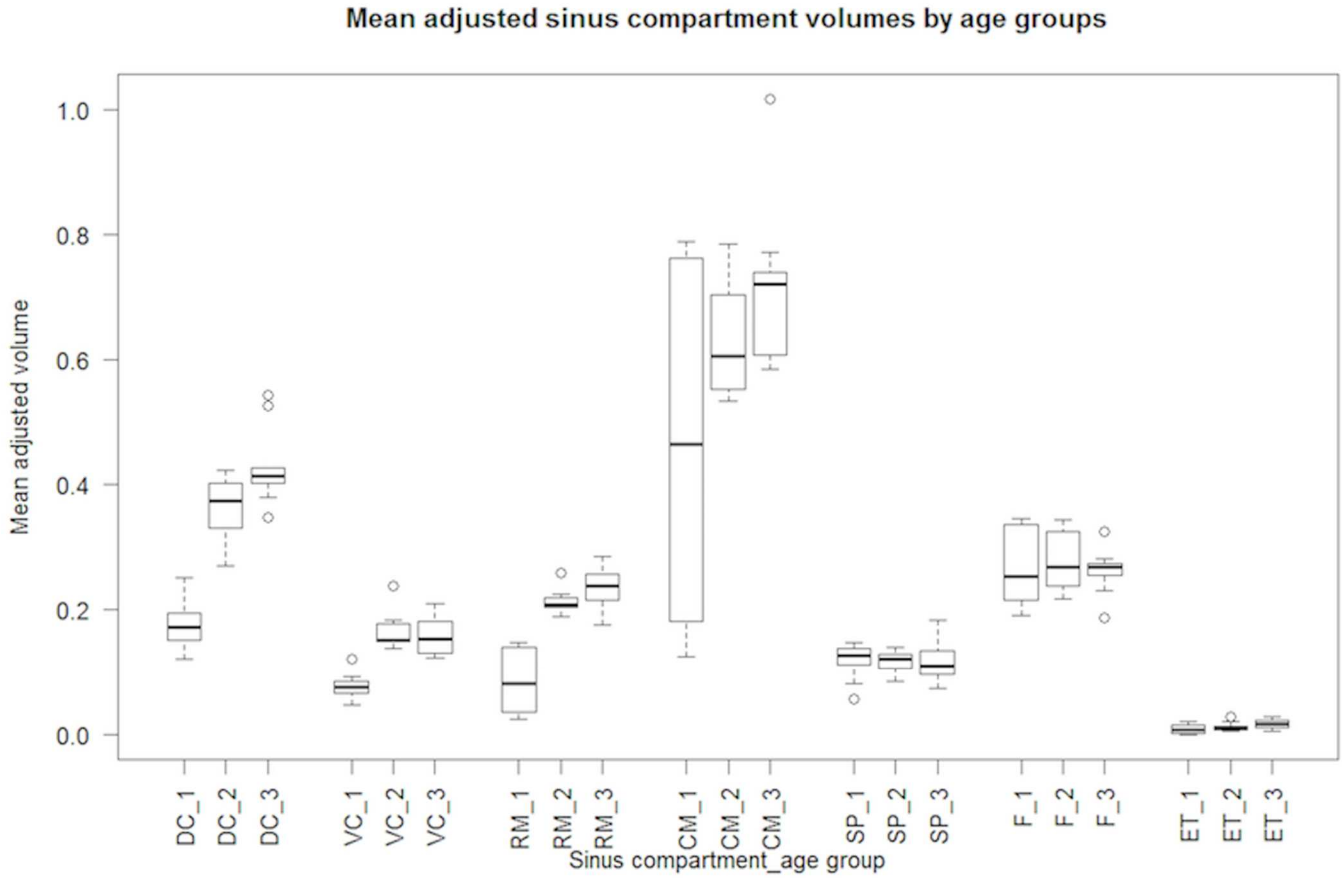

Fig. 5 **Mean adjusted sinus compartment volumes subdivided by age groups. Sinus compartments: DC=dorsal conchal; VC=ventral conchal; RM=rostral maxillary; CM=caudal maxillary; SP=sphenopalatine; F=frontal; ET=ethmoidal. Age groups: 1=<6 years old; 2=6-15 years old; 3=>15 years old. Lower and upper box lines=25th and 75th percentiles, respectively; Middle box line in bold=median; lower and upper whiskers=lower and upper adjacent values, respectively; open circles=outliers.**

Results

Gross observations

All 90 heads, including the 26 with sinonasal or significant maxillary cheek teeth disorders, had grossly intact maxillary septae, including the dorsally situated maxillary septal bulla (previously misnamed "ventral conchal bulla") that was often not fully detectable on CT imaging. There was much variation in the overall size and shape of this bulla, i.e. in how far caudally, dorsally and latero-medially it protruded into the caudal maxillary sinus.

Position of cheek teeth in relation to the maxillary sinuses

The alveoli of the maxillary: 06s and 07s were not in contact with any sinus lumen in any age group; All 08s were partly or fully within the RMS; 09s were fully within the RMS in all, except two young (1.5 and 2-year-old) cases where they were fully in the CMS; 10s were variably in the RMS or CMS; and 11s were consistently within the CMS (Table 1).

Triadan	Group 1 (<6 y.o.) (N=15)	Group 2 (6-15 y.o.) (N=21)	Group 3 (>15 y.o.) (N=24)
106/206	N/A	N/A	N/A
107/207	N/A	N/A	N/A
108/208	RMS (7) p RMS (8)	RMS (18) p RMS (3)	RMS (22) p RMS (2)
109/209	RMS (13) CMS (2)	RMS (21)	RMS (24)
110/210	RMS (6) CMS (9)	RMS (15) CMS (6)	RMS (11) CMS (9) R/CMS (4)
111/211	CMS (8) N/A (7)	CMS (21)	CMS (24)

Table 1

Location of dental alveoli in relation to the maxillary sinuses in 60 heads. y.o. = years old; N/A=not in any sinus; RMS=rostral maxillary sinus; CMS=caudal maxillary sinus; R/CMS= partly in rostral and caudal maxillary sinuses; p= alveolus partly in sinus.

Position of the IOC in relation to cheek teeth alveoli

In the nine youngest horses (aged 1-2 years old) the IOC lay in direct contact with the medio-dorsal aspect of the alveolus (Fig 3), appearing to share a common bony wall initially. In the 51 horses older than two years, the IOC ran dorso-medial to the maxillary cheek teeth alveoli, connected only by a bony septum that increased in height with age and dental eruption. There was no significant difference in the distance between the dental apices and the IOC: between left and right sides; rostral and caudal roots, and Triadan positions. As expected, the distance between the dental apices and the IOC increased with age (Table 2).

The distance between the IOC and the medial (horizontal measurement) or dorsal (vertical measurement) wall of the VCS (Fig 4) i.e. the narrowest and widest aspects of the concho-maxillary ostium showed no significance difference between left and right side ($p>0.8$) and mean values are given in Table 3.

Triadan position	**Age group 1** **<6 yo**	**Age group 2** **6-15yo**	**Age group 3** **>15yo**
08	0.8	1.5	2.6
09	1.7	2.5	4
10	0.6	1.5	3.6
11	0.5	1.3	3.4
Mean of all teeth	0.9	1.7	3.4

Table 2

Mean distances (cm) between the dental apices and the infraorbital canal (IOC) in horses of different ages

Plane of measurement	Age Group	**1**	**2**	**3**
Horizontal	At Triadan 10	0.3	0.6	0.6
Horizontal	At Triadan 11	0.4	0.9	0.8
Vertical	At Triadan 10	1.7	3.1	2.2
Vertical	At Triadan 11	1.9	2.9	2.4

Table 3

Mean distance (cm) between the IOC and the medial and dorsal walls of ventral conchal sinus (conchomaxillary opening) level with Triadan 10 and 11 positions.

Rostral migration of maxillary cheek teeth

The distances between the caudal aspects of the Triadan 11 clinical crowns and apices and the reference site (orbital rim) were measured in the 53/60 heads where the Triadan 11 teeth had erupted. There was no significant difference between the left and right side measurements, and means of these values were subsequently used for statistical analyses

In 5/8 heads in Group 1 (<6 years old) and in 6/21 heads of Group 2 (6-15 years old), the caudal aspect of the clinical crown of the Triadan 11s lay caudal to the orbital reference line. Because of the caudally directed curvature of the Triadan 11s, the caudal aspect of the apices in all (8/8) heads in Group 1 and 10/21 heads in Group 2 lay caudal to the orbital rim.

In all other heads, both dental landmarks were rostral to the orbital rim. The mean absolute (and adjusted) distances between the orbital landmark and: the caudal clinical crown; and the apices of the Triadan 11s are shown in Table 4 The adjusted mean distances were significantly different between age groups for both the caudal clinical crown ($F[2,50]=17.15$, $P<0.001$) and apices ($F[2,50]=15.85$, $P<0.001$), with the mean absolute (and adjusted) distance of the clinical crowns and apices of the Triadan 11s in Group 3 (>16 years old) being 2.48 cm (5.2%) and 2.83 cm (6.2%) more rostral respectively, than those in Group 1 (<6 years old).

	Group 1 (<6 years old)		Group 2 (6-15 years old)		Group 3 (>15 years old)	
Orbital landmark to:	Mean (SD) absolute distance (cm)	Mean (SD) adjusted distance (%)	Mean (SD) absolute distance (cm)	Mean (SD) adjusted distance (%)	Mean (SD) absolute distance (cm)	Mean (SD) adjusted distance (%)
Caudal clinical crown	0.28 (1.3)	0.8 (2.7)	-0.7 (1.2)	1.4 (2.5)	-2.2 (1.2)	-4.4 (2.2)
Apices of Triadan 11	2.3 (1.4)	5.1 (3.4)	0.5 (1.6)	1.1 (3.3)	-0.53 (0.9)	-1.1 (1.8)

Table 4

The mean absolute (and adjusted) distances between the rostral orbital landmark and the caudal clinical crown; and the apices of the Triadan 11s. SD=Standard deviation.

Length of reserve crown in maxillary cheek teeth

Mean absolute (and adjusted) reserve crown lengths, for each Triadan position and age group are shown in Table 5. There was no statistical difference between left and right side reserve crown lengths, and mean values were used for comparison between age groups. Mean adjusted reserve crown lengths differed significantly between age groups for each Triadan position: 06 ($F[2,57]=29.13$, $P<0.001$); 07 ($F[2,57]=23.53$, $P<0.001$); 08 ($F[2,57]=14.58$, $P<0.001$); 09 ($F[2,57]=47.56$, $P<0.001$); 10 ($F[2,57]=59.06$, $P<0.001$); and 11 ($F[2,57]=8.25$, $P<0.001$) with length decreasing with age.

Triadan tooth	Group 1 (<6 years old)		Group 2 (6-15 years old)		Group 3 (>15 years old)	
	Mean (SD) absolute length (cm)	Mean (SD) adjusted length (%)	Mean (SD) absolute length (cm)	Mean (SD) adjusted length (%)	Mean (SD) absolute length (cm)	Mean (SD) adjusted length (%)
06	4.1 (1.3)	17.0 (5.3)	3.3 (0.7)	11.9 (2.4)	2.3 (0.7)	8.4 (2.6)
07	4.8 (1.5)	19.9 (6.0)	4.5 (0.7)	16.0 (3.3)	3.0 (0.9)	10.8 (3.4)
08	4.5 (1.8)	18.5 (6.6)	5.1 (0.9)	18.4 (3.9)	3.3 (1.0)	11.8 (3.8)
09	5.5 (1.0)	23.5 (6.1)	4.3 (0.8)	15.4 (3.3)	2.8 (1.0)	9.9 (3.5)
10	6.1 (0.8)	25.6 (4.3)	5.0 (1.0)	17.7 (3.9)	3.2 (1.0)	11.4 (3.8)
11	3.5 (2.4)	13.9 (9.2)	4.8 (0.9)	17.2 (3.9)	2.9 (1.0)	10.4 (3.7)

Table 5

Mean (of left and right sides) absolute and adjusted reserve crown lengths, subdivided by Triadan position and age group. Adjusted reserve crown length calculated as a percentage of measured head height.

Sinus volumes

There were no significant differences in individual sinus compartment volumes between left and right sides; consequently all further analyses used the mean of left and right measurements. The mean volumes of sinus compartments from the 30 measured skulls and the details of sinus volumes, subdivided by age group are shown in Table 6. When accounting for age group, the DCS was larger than the FS in Group 2 (6-15 year old) horses - (121.1 cm^3 vs 85.1 cm^3) and Group 3 (> 15 year old) horses (126.6 cm^3 vs 79.7 cm^3) but not in Group 1 (<6 year old) horses (37.3 cm^3 vs 56.7 cm^3) where these compartments were incompletely developed.

The volumes of the two intra-conchal sinuses greatly differed, with the DCS approximately 2-3 times larger than the VCS in all age groups; Group 1 (37.3 cm^3 vs 15.5 cm^3 respectively), Group 2 (112.1 cm^3 vs 49.3 cm^3) and Group 3 (126.6 cm^3 vs 46.5 cm^3). Details of sinus volumes, subdivided by compartment and age group are shown in Table 6.

The mean "head" volume from the 30 measured skulls was 27,175 cm^3 (range 9,405 to 37,758 cm^3) in comparison to a mean volume of 31,777 cm^3 (range 25,194 cm^3 to 37,076 cm^3) in the known Thoroughbred group (n=12). All individual sinus compartment volumes were significantly positively associated with head volume. The results of the linear regression analyses are shown in Table 7.

The adjusted sinus compartment volumes differed significantly between age groups for all except the SPS and the FS Table 6. Graphical representation of the spread of adjusted sinus compartment volumes for the different age groups is shown in Fig. 5.

	Mean (SD) sinus volume (cm^3)	**Mean (SD) sinus volumes (cm^3) by age group**			**ANOVA comparisons of adjusted sinus volumes between age groups**
Paranasal Sinus		Group 1 (<6 years old)	Group 2 (6-15 years old)	Group 3 (>15 years old)	
Dorsal conchal	92 (43)	37.3 (15.4)	112.1 (24.6)	126.6 (8.7)	$F[2,27]=70.94$, **$P<0.001$**
Ventral conchal	37 (17)	15.5 (5.2)	49.3 (8.7)	46.5 (4.4)	$F[2,27]=31.8$, **$P<0.001$**
Rostral maxillary	52 (27)	20.8 (17.0)	64.5 (12.7)	70.3 (15.0)	$F[2,27]=43.63$, **$P<0.001$**
Caudal maxillary	175 (82)	112.4 (87.2)	193.9 (49.4)	219.7 (67.9)	$F[2,27]=5.05$, **$P=0.0137$**
Sphenopalatine	31 (9)	25.3 (10.8)	35.5 (7.3)	33.4 (6.1)	$F[2,27]=0.07$ $P=0.9343$
Frontal	73 (24)	56.7 (22.4)	85.1 (24.0)	79.7 (18.6)	$F[2,27]=0.30$ $P=0.7445$
Ethmoidal	4 (3)	2.4 (2.2)	4.0 (2.3)	5.6 (2.7)	$F[2,27]=3.38$, **$P=0.0491$**

Table 6

Average sinus volumes measured by computed tomography in 30 horses subdivided by compartment, average sinus volume subdivided by age group and results of ANOVA comparisons of sinus volumes (adjusted to head size) between age groups. SD=Standard deviation; F=F-value, figures in square brackets refer to the degrees of freedom for the effect and the degrees of freedom for the error term respectively; Significant P-Values in bold.

Sinus	Coefficient	Lower 95% C.I.	Upper 95% C.I.	Standard Error	P-value
Dorsal conchal	0.0047	0.0033	0.0060	0.0007	<0.001
Ventral conchal	0.0016	0.0010	0.0022	0.0003	<0.001
Rostral maxillary	0.0032	0.0025	0.0038	0.0003	<0.001
Caudal maxillary	0.0100	0.0082	0.0119	0.0009	<0.001
Sphenopalatine	0.0009	0.0006	0.0012	0.0002	<0.001
Frontal	0.0029	0.0022	0.0035	0.0003	<0.001
Ethmoidal	0.0002	0.0001	0.0003	0.0000	<0.001

Table 7

Results of linear regression analysis of sinus compartment volumes compared to head volumes, measured in 30 equine heads.

Discussion

It is commonly stated that the alveoli of the maxillary Triadan: 06-07 lie in the maxillary bone; 08-09 lie within the RMS/VCS; and 10-11 lie within the CMS, in young-adult horses (Dixon and others 2009), but little objective information on the intra-sinus disposition of these alveoli is available. The current study found the Triadan 09 alveoli to be located in the CMS in only 2/15 (13%) of the youngest group and the Triadan 10 alveoli to be fully positioned in the RMS in 53% of all cases (32/60 heads). The difference between this finding and conventionally accepted information is difficult to explain, but may be related to variation in the site and in the degree of caudo-medial obliquity of the maxillary septum. The rostral aspect of the maxillary septum was reported to be rostral to the 09s in 47% of cases and to the 10s in 44% of cases in a previous study (Brinkschulte and others 2013). However, the variation in the obliquity of the maxillary septum means that assessment of the intra-sinus position of each tooth has to be assessed over the full width of each alveolus.

Knowledge of the position of the IOC in relation to the cheek teeth apices is important to understand its susceptibility to damage from apical infection, and to avoid its damage during dental repulsion or sinus surgery (Tremaine 2006, Dixon and others 2009). The intimate relationship of this canal and the medial aspect of the maxillary cheek teeth alveoli in horses <2 years of age also makes the IOC susceptible to damage from extension of apical infection (Easley and Freeman 2013) In this study all horses older than two years of age had complete separation of the IOC and the apices of all the maxillary cheek teeth, despite root elongation with cementum following eruption (Sisson and Grossman 1953, Dixon and du Toit 2011). In horses < 6 years (Group 1), the IOC was closer (mean distance 0.9cm) to the dental apices than in older horses (1.7cm in 6-15 y.o group and 3.4cm in the >15yo group) making sinus surgery (particularly of the RMS) in younger horses more challenging. These finding also indicate that drainage of the VCS into the RMS by fenestrating the septum between IOC and dental apex is only practical in horses circa 15 years old and older.

Probst and others (2005) reported the conchomaxillary opening to be 1- 8mm wide, but did not describe age-related differences in this parameter. In this study, both the narrowest and widest sites were measured and younger horses were found to have a smaller conchomaxillary opening than older horses, likely due to the large reserve crown within the VCS narrowing of this ostium (Fig 6).

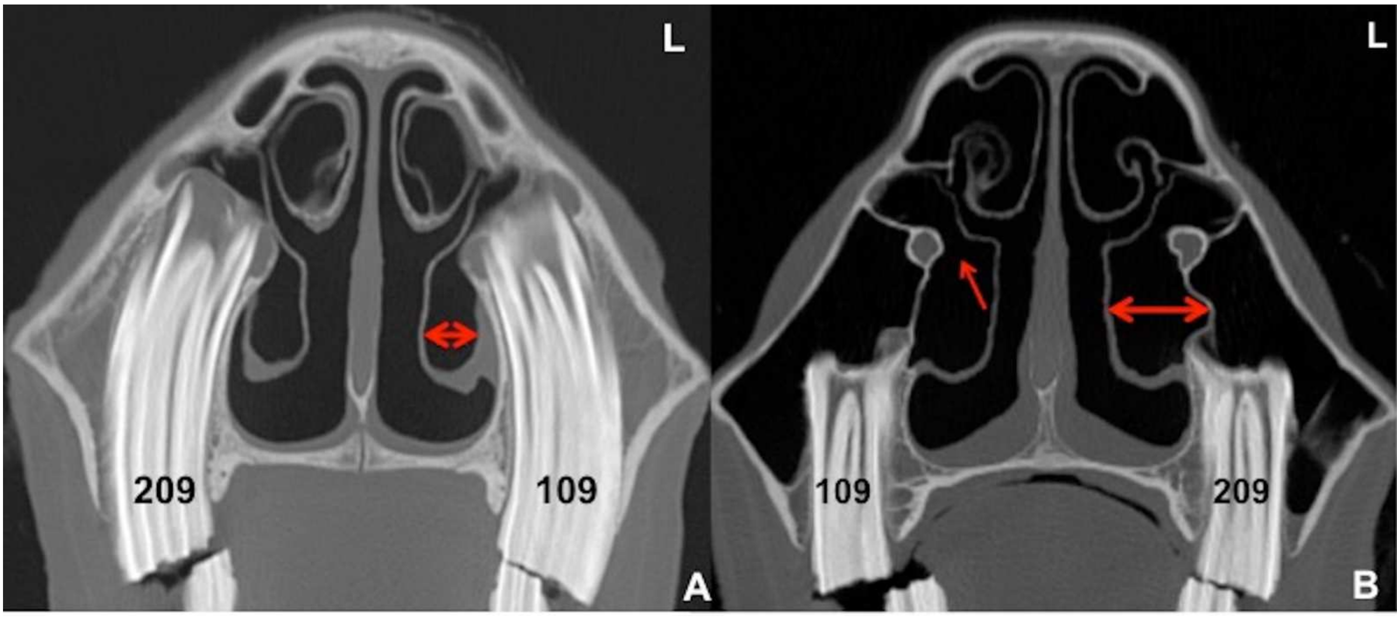

Fig. 6 **Transverse CT image of a 1 year old horse (A) and a 10 years old horse (B) at the level of Triadan 09. Note the compression of the VCS (double arrow head) by the tall reserve crowns in the young horse as compared to the adult horse, and the height of the septum beneath the infraorbital canal that separates the VCS and the RMS (red arrow) in the mature horse. L:** ***Left***

The small dimensions of the conchomaxillary ostium (mean of 6mm in adults) readily explains why with sinus inflammation and mucosal thickening, it will become sealed such that the VCS loses its drainage into the RMS.

Equine cheek teeth normally drift in a rostral (mesial) direction with age (Sisson and Grossman 1953), which is likely contributed to by the continued eruption of the rostrally angulated clinical crowns (caudally angulated reserve crowns) of the caudal cheek teeth, especially the 11s (equivalent to the “wisdom tooth” in humans) (Dixon and du Toit 2011). Post-eruptive dental movement in brachydont teeth compensates for interproximal wear and the rostrally (mesially) directed brachydont dental drift is mainly caused by normal occlusal forces and by trans-septal ligament contraction (Dyce and others 2011). Such rostral drift is additionally needed by equine teeth because they taper in towards their apices, thus making the clinical crown smaller with age (Dixon and du Toit 2011), but in contrast to some brachydont species, equine dental drift is restricted by the caudally angulated Triadan 06. The presence of effective rostral dental drift can bring and also keep the occlusal aspects of cheek teeth in tight contact and thus can resolve cheek teeth diastemata in younger horses and continually prevent it in adults. Rostral drift also influences the degree and speed of post extraction site closure.

In the current study, the mean positions of the clinical crowns and apices of the Triadan 11s were 2.48 cm (adjusted 5.2%) and 2.83 cm (adjusted 6.2%) more rostral, respectively in the oldest than the youngest group, consistent with dental drift. The caudal aspect of the 11s can demonstrate more dramatic changes in position as the more horizontal aspect of this curved tooth erupts and thus shortens the tooth. However the variable laying down of root cementum that elongated the apical aspect of some teeth, made the apex a less reliable landmark than the crown to assess dental drift. These measurements on dental drift could provide further objective radiographic guidelines on ageing horses by dental imaging.

Equine dental reserve crown length decreases with age, but this prolonged eruption has not been well quantified. The reserve crown length decreased from a mean of 4.7 cm (adjusted length 19.7%) of all 12 teeth in the youngest (<6yo) horses to a mean of 2.9 cm (adjusted length 10.5%) in the oldest group (>156yo), with the 06s and 09s having the shortest reserve crowns. The horse heads in this study were all aged by their dentition into 5-year groupings. Due to the limitations of these dental ageing techniques, it is possible that some heads could have been placed into an incorrect age group. A study where the exact age of each horse was known would provide more valuable information in this regard. A small number of horses were borderline for placement in the 6-15yo group or alternatively the >15yo group, but following further examinations a consensus was reached to allow them to be placed in one group. The use of CT images of clinical cases without identifiable cheek teeth abnormalities would allow a more precise ageing of cases, but would not allow the anatomical head dissections that were performed on most of these heads to verify the imaging findings.

The concept of two functional sinus compartments termed the rostral and caudal sinus systems (O'Leary and Dixon 2011, Brinkschulte and others 2013,) was supported in this study by the presence of an intact maxillary septum on gross examinations in all 90 heads originally examined, including those with sinonasal or significant dental disease, where the maxillary septum was sometimes thickened but never perforated, as was found in 2.5% of sinusitis cases in one clinical study (Dixon and others 2012).

No significant differences were found between left and right individual sinus compartment volumes as previously noted (Brinkschulte and others 2013). Significant age-related increases in sinus compartment volumes were observed for the DCS, VCS, CMS, RMS, SP, but not for the small ES and large FS. Brinkschulte and others (2013) also found that most age-related differences in volume occurred in the RMS, VCS and CMS compartments (Brinkschulte and others 2013) all which contain dental alveoli and so would be expected to increase in volume with dental eruption (Dyce and others 2010, Sisson and Grossman 1953) The volume of the other sinus compartments are unaffected by dental eruption, but growth in head size would influence the dimensions of all sinus compartments in the younger group. Similar to previous findings (Brinkschulte and others 2013) the current study identified a significant positive association between head volume and the individual sinus compartment volumes.

The sinus compartment volumes found in this study (Table 6) were similar to those of the Brinkschulte and others (2013) study where 14/18 examined horses were Warmbloods, of a similar age distribution to the current study. The main difference between the current findings and those of the previous study (Brinkschulte and others 2013) were the much smaller FS and larger DCS volumes found in the current study, i.e. means of 73.8 cm^3 and 92 cm^3 respectively vs means of 186.0 cm^3 for FS vs 41.7 cm^3 for DCS by Brinkschulte and others (2013). Whilst different methodologies were used to assess volumes in these two studies, the above discrepancy is most likely due to differences in the convoluted boundary used to separate the DCS and FS in these two studies, because the combined values of the FS and DCS (i.e. the conchofrontal sinus) was very similar between studies, i.e. 204.7 cm^3 in the current vs 227.8 cm^3 in the previous study (Brinkschulte and other 2013). Inter-study differences in results may also reflect breed differences between the two studies as no breed information was available for the 30 heads used in the current study, although as shown, they were similar to the size of Thoroughbreds to that are somewhat smaller than the Warmbloods used by Brinkschulte and others (2013), but overall, this larger study validates the former study. The small size of the VCS (mean volume 37 cm^3; SD=17 cm^3) can explain the difficulty in performing sinoscopy on this compartment in some, especially in younger horses.

Multiple studies have reported the use of three-dimensional (3-D) computed tomography to assess: normal human sinus anatomy during development (Kawarai and others 1999, Park and others 2010), sinus fractures (Belina and others 2009) and to develop a staging system to correlate symptoms with radiological imaging results in patients with chronic rhinosinusitis (Deeb and others 2011) Potentially, future equine CT studies could provide a similar grading system to guide treatment in cases of primary sinusitis.

Animal welfare

This study was approved by the Royal (Dick) School of Veterinary Studies and the Royal Veterinary College Ethical Review Committees.

Conflict of interest statement

No actual or potential conflict of interest including any financial, personal or other relationship with other people or organization within three years of beginning the submitted work exists.

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Submission declaration and verification

This original study has not been published previously, it is not under consideration for publication elsewhere, its publication is approved by all authors and tacitly an explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or any other language, including electronically without the written consent of the copy-right holder.

References

Bahar, S., Bolat, D., Dayan, M.O. and Paksoy, Y. (2014) Two- and three-dimensional anatomy of paranasal sinus in Arabian foals. *Journal of Veterinary Medical Sci*ence **76**, 37-44

Belina, S., Cuk, V., Klapan, I. (2009) Virtual endoscopy and 3D volume rendering in the management of frontal sinus fractures. *Collegium Antropologicum* **33**, 43-51.

Brinkschulte, M., Bienert-Zeit, A., Lupke, M., Hellige, M., Ohnesorge, B. and Staszyk, C. (2014) The sinonasal communication in the horse: examinations using computerized three-dimensional reformatted renderings of computed-tomography datasets. *BMC Veterinary Research* **10**, 72.

Brinkschulte, M., Bienert-Zeit, A., Lupke, M., Hellige, M., Staszyk, C. and Ohnesorge, B. (2013) Using semi-automated segmentation of computed tomography datasets for three-dimensional visualization and volume measurements of equine paranasal sinuses. *Veterinary Radiology & Ultrasound*. **54**, 582-590.

Brown, S.L., Arkins, S., Shaw, D.J. and Dixon, P.M. (2008) Occlusal angles of cheek teeth in normal horses and horses with dental disease. *Veterinary Record* **162**, 807-810.

Buhler, M., Furst, A., Lewis, F.I., Kummer, M. and Ohlerth S. (2014) Computed tomographic features of apical infection of equine maxillary cheek teeth: A retrospective study of 49 horses. *Equine Veterinary Journal* **46**, 468-473

Deeb, R., Malani, P.N., Gill, B., Jafari-Khouzani, K.,Soltanian-Zadeh, S.,Patel, S., Zacharek, M.A.,(2011) Three-dimensional volumetric measurments and analysis of the maxillary sinus. *The American Journal Rhinology & Allergy* **25**: 152-156

Dixon, P.M., du Toit, N., (2011) Dental Anatomy. In *Equine Dentistry*, Eds. J Easley, P.M. Dixon and J Schumacher3rd edn: Elsevier, Saunders, p51-76.

Dixon, P.M., Froydenlund, T., Liuti, T., Kane-Smyth, J., Horbal, A. and Reardon, R.J. (2015) Empyema of the nasal conchal bulla as a cause of chronic unilateral nasal discharge in the horse: 10 cases (2013–2014). *Equine Veterinary Journal* **47**, 445-449.

Dixon, P.M., Hawkes, C., Townsend, N. (2009) Complications of Equine Oral Surgery. In *Veterinary Clinics of North America-Equine Practice*, edn*:* Elsevier Saunders, p 499-512

Dixon, P.M., Parkin, T.D., Collins, N., Hawkes, C., Townsend, N., Tremaine, W.H., Fisher, G., Ealey, R. and Barakzai, S.Z., (2012). Equine paranasal sinus disease: a long-term study of 200 cases (1997–2009): treatments and long-term results of treatments. *Equine Veterinary Journal* **44** 272-276.

Dyce, K.M., Sack, O.W. and Wensing, C.J.G. (2010) The head and ventral neck of the horse. In: Textbook of Veterinary Anatomy, 4th edn., Elsevier, Saunders, Edinburgh. pp 479-509.

Easley J.T and Freeman D.E (2013) New ways to diagnose and treat equine dental-related sinus disease. In: *The Veterinary clinics of North America. Equine Practice* **29** (467-485)

Henninger, W., Frame, M., Willmann, M., Simhofer, H., Malleczek, D., Kneissl, S. and Mayrhofer, E. (2003) CT features of alveolitis and sinusitis in horses. *Veterinary Radiology & Ultrasound* **44**, 269-276.

Kawarai, Y., Fukushima, K., Ogawa, T., Nishizaki, K., Gunduz, M., Fujimoto, M., Masuda, Y. (1999) Volume quantification of healthy paranasal cavity by three-dimensional CT imaging. *Acta Otolaryngologica* Suppl. 540, 45–49.

Liuti, T., Reardon, R., Smith, S. and Dixon, P.M. (2015) An anatomical study of the dorsal and ventral nasal conchal bullae in normal horses: computed tomographic anatomical and morphometric findings. *Equine Vet. J.* **6** DOI: 10.1111/evj.12516

Morrow, K.L., Park, R.D., Spurgeon, T.L., Stashak, T.S. and Arceneaux, B. (2000) Computed tomographic imaging of the equine head. *Veterinary Radiology & Ultrasound*. **41**, 491-497.

Muylle, S. 2011; Ageing. In *Equine Dentistry*, Eds. J Easley, P.M. Dixon and J Schumacher 3rd edn: Elsevier, Saunders, St Louis pp 85-96

O'Leary, J.M. and Dixon, P.M. (2011) A review of equine paranasal sinusitis. Aetiopathogenesis, clinical signs and ancillary diagnostic technique. *Equine Veterinary Education* **23**, 148-159.

Park, I.H., Song, J.S., Choi, H., et al. (2010) Volumetric study in the development of paranasal sinuses by CT imaging in Asian: a pilot study. *International Journal of Pediatric Otorhinolaryngology* **74**, 1347–1350.

Probst, A., Henninger, W. and Willmann, M. (2005) Communications of normal nasal and paranasal cavities in computed tomography of horses. *Veterinary Radiology & Ultrasound*. **46**, 44-48

Sisson, S. and Grossman, J.D. (1953) The digestive system. In: *The Anatomy of the Domestic Animals*, 4th edn revised.., WB Saunders Co, Philadelphia. pp 463-487

Solano, M., Brawer, R.S. (2004) CT of the equine head: technical considerations, anatomical guide, and selected diseases. *Clinical Techniques in Equine Practice*. **3**, 374–388.

Tremaine, W.H., (2006) Complications associated with dental and paranasal sinus surgery. Published in IVIS with the permission of the AAEP

Veraa, S., Voorhout, G. and Klein, W.R. (2009) Computed tomography of the upper cheek-teeth in horses with infundibular changes and apical infection. *Equine Veterinary Journal* **41**, 872-876.

Windley, Z., Weller, R., Tremaine, W.H. and Perkins, J.D. (2009) Two-dimensional and three-dimensional computer tomographic anatomy of the enamel, infundibulae and pulp of 126 equine cheek-teeth. Part 1: findings in teeth without macroscopic occlusal or computer tomographic lesions. *Equine Veterinary Journal* **41**, 433-440